CASP

BBC RD 1976/6

BBC

RESEARCH DEPARTMENT

1969 1974
THE QUEEN'S AWARD TO INDUSTRY

REPORT

Diversity reception at high-frequencies using the single-sideband mode

D.E. Susans, C.Eng., M.I.E.E., M.I.E.R.E.

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION February 1976

BBC RD 1976/6
UDC 621.391.85:
621.3.029.5

DIVERSITY RECEPTION AT HIGH-FREQUENCIES USING THE SINGLE-SIDEBAND MODE

D.E. Susans, C.Eng., M.I.E.E., M.I.E.R.E.

Summary

When using long-distance h.f. s.s.b. re-broadcast links it is customary to use dual-diversity reception. This method of reception has considerable advantages over a single-channel under conditions of 'flat' fading but it has been reported that any improvement is only marginal when the fading is predominantly frequency-selective. The reasons for this are discussed and a new correlation method of combining the audio outputs of a diversity receiver is suggested. Subjective tests on an experimental correlation combiner have demonstrated improved reception quality.

Issued under the authority of

P. Rainger

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

February 1976

(EL-111)

DIVERSITY RECEPTION AT HIGH-FREQUENCIES USING THE SINGLE-SIDEBAND MODE

DIVERSITY RECEPTION AT HIGH-FREQUENCIES USING THE SINGLE-SIDEBAND MODE

D.E. Susans, C.Eng., M.I.E.E., M.I.E.R.E.

1. Introduction

When receiving h.f. double-sideband transmissions using conventional receivers, it has been known for very many years that there is a considerable advantage if diversity reception is employed. However, if modern independent sideband receivers are used in place of envelope-detector receivers, thereby giving better single-channel reception, the further advantage of diversity is limited with present methods of combining. There remains a considerable amount of distortion particularly under frequency-selective fading conditions. Such conditions occur when the signal arrives at the receiver by two or more paths with different propagation delays. Typical delay differences are of the order of 1 ms. Path differences between the components of the received signal give rise to a number of minima in the modulation frequency response, that is, they generate a 'comb-filter' effect. The frequencies of the 'teeth' of the comb, in general, move steadily through the band as small changes in path-length occur. Two well-spaced aerials will pick up signals which differ in the relative phases of the component signals and will thus have differing frequencies for the teeth of the comb. Intuitively it is expected that it should be possible to combine two such signals so as to get a better overall response. However, finding a satisfactory way to combine the signal is not a simple task.

Subjective tests described in Section 7, using a two-channel single-sideband (s.s.b.) receiver for diversity reception, include observations when the audio signals were simple added. The results show that, whilst there is the expected improvement under single-path fading conditions, when frequency-selective fading is present there is, on average, little improvement.

Further investigation shows that, for a large part of the time, it is possible to find an optimum phase in which to add the two audio outputs of a diversity receiver, but that this optimum phase continually changes, often at a rate in excess of 10 radians/s. If a method could be found of determining this optimum phase and then using it in adding together the two audio signals, the distortion produced by the selective fading could be substantially reduced. Section 6 describes equipment to carry out this operation whilst Section 7 describes the related subjective tests. These tests include comparisons with combining-methods using delay-lines.

2. Envelope detection

During selective fading conditions, the carrier is occasionally cancelled. At and near to this condition, the effective depth of modulation is considerably increased and this gives rise to non-linear distortion in h.f. receivers using envelope detection. In some cases, the detected audio modulation appears as if it had been passed through a rectifier circuit.

Carrier cancellation will not normally occur simultaneously in both channels of a diversity receiver and addition of the two audio signals thus gives a large improvement in quality over single-channel reception, although

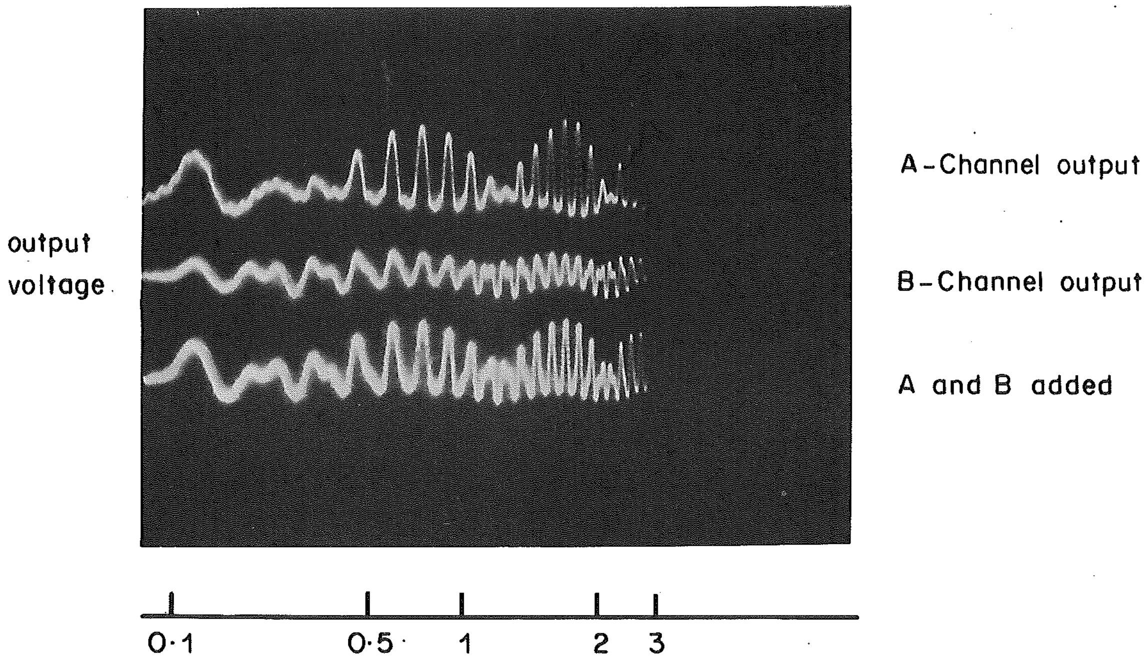

Fig. 1 - Envelope detector audio-frequency output signal voltages vs modulating frequency

there is still a very considerable amount of distortion present. This can be seen in Fig. 1 which shows the display of the output signal voltages obtained using a swept-frequency modulating audio input signal and the fading simulator described in the Appendix. The figure shows the outputs obtained simultaneously from the two individual channels A and B, together with their sum.

3. Synchronous detection

Overmodulation or 'rectifying' distortion as described in Section 2, can be almost completely removed by using synchronous detectors. The distortion that then remains is the frequency-selective distortion referred to in Section 1.

If the transmission is single-sideband it is essential to use synchronous detection, but this method of detection can also be used on double-sideband transmissions, preferably in a single-sideband mode, to give immunity from overmodulation distortion.

When synchronous detectors are used, it is found that dual-diversity operation is still advantageous in reducing the effects of fading; as already stated, however, it does not reduce the combing (or variations in level over the audio-frequency band) brought about by multipath fading. We can see why this is from an examination of swept-frequency displays, such as those of Fig. 2. Here, after passing through the fading-simulator, the two s.s.b. signals were synchronously detected and added.

Although the minima appear at different frequencies in the two channels, for every minimum in one channel a minimum was created at a new frequency in the combined channel. The exact positioning of these minima depends upon the relative phasing of the two signals.

It is this generation of new minima which prevents the simple addition of the two diversity signals from improving reception under frequency-selective fading conditions. However, it should be remembered that, under other fading conditions, diversity operation does give a substantial improvement both in reduction of fading and reduction in noise.

4. Dual-diversity receiver

It was important to ensure that laboratory test comparisons were made with the optimum type of receiver operation, whether in single- or dual-channel modes. A Plessey model PRD 200 receiver was suitably modified to achieve this; most of the modifications were, in effect, to provide the facilities of a later commercial version of this receiver.

The receiver covers the high-frequency band of 3 to 30 MHz and has available two separate channels A and B. As modified, the receiver channels could use, for synchronous detection, either a common output from the frequency-synthesiser or two independent sources derived from the filtered and limited incoming carrier. The audio bandwidth normally used was 6 kHz although both 3 and 4·5 kHz options were available. Care was taken to adjust the phase matching of the two channels so that, in non-fading conditions, the two audio outputs were co-phased.

5. Automatic gain-control

5.1. General

It is common practice in receivers to use automatic gain-control (a.g.c.) circuits that develop a control voltage

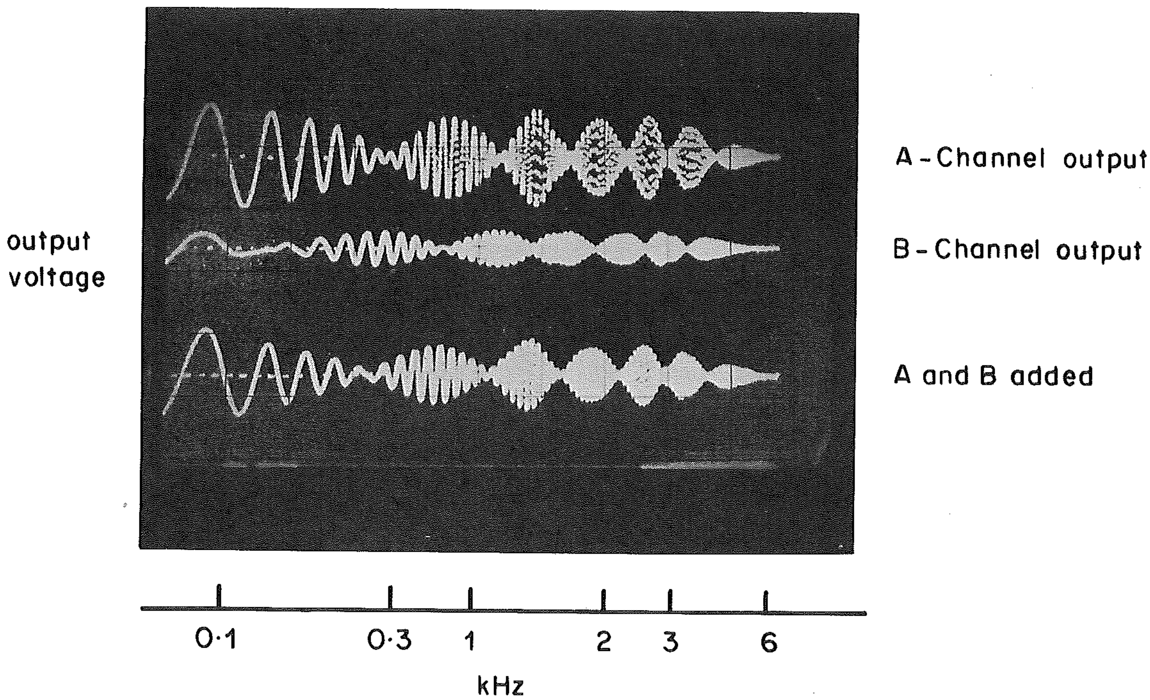

Fig. 2 - Synchronous detector audio-frequency output signal voltages vs modulating frequency

from the received signal. This is satisfactory with envelope detection and for 'flat' fading with synchronous-detector receivers. In synchronous-detector receivers where the a.g.c. is derived from the carrier only, there is no protection against the severe overloading which occurs during deep carrier fades, under selective-fading conditions. The sidebands, in general, do not suffer the same reduction in level as the carrier and are boosted in amplitude as the a.g.c. compensates for the fading carrier; this can lead to overloading in subsequent stages of the receiver. In diversity reception, the incidence of the distortion can be reduced by linking the a.g.c. circuits of the two channels (see Section 5.2 below); however, this method cannot prevent distortion when both carriers fade together.

This effect was avoided in the laboratory tests by deriving additional a.g.c. control voltages for each of the two diversity channels from detectors driven from the sideband signals and using these control voltages so that, if the effective percentage-modulation exceeded, say, 80%, then the sideband a.g.c. predominated; otherwise the a.g.c. was controlled by the carrier.* An incidental effect of this was to give programme compression during the short periods when overload would otherwise have occurred.

5.2. AGC linking circuits

Two methods of linking a.g.c. circuits of the diversity receiving channels may be used, depending on the type of audio combining circuit, the type of fading and the general noise level. First, direct linking of the a.g.c. lines, which gives a rapid changeover to the stronger channel, is often recommended for use in conditions of high noise-levels, 'flat' fading and direct addition of the audio output signals. Secondly, if an improved audio combiner is used which makes simultaneous use of both audio signals, then the method should be used whereby the two channels have independent a.g.c. circuits, as long as one of the r.f. signals is not excessively noisy.

In practical systems, both of these methods have their limitations. With the first method, any gain-differences between the receivers, feeder systems or aerial arrays can mean that, for a large part of the time, only one channel is effective. With the second method, if one of the r.f. signals suffers a deep fade or one of the receiver channels fails, a large noise output may be obtained which spoils the audio output signal.

If the direct link between the a.g.c. control lines is replaced by an a.c.-coupling with a time-constant of, say, one minute, then the two channels will have a.g.c. circuits that, in the long-term remain independent; however short-term fluctuations of carrier levels will be treated as if the control lines were directly linked. To avoid the problem of excessive noise in the event of a long fade or a channel failure, antiparallel diodes across the capacitor can also be used to limit the difference between the channel a.g.c.

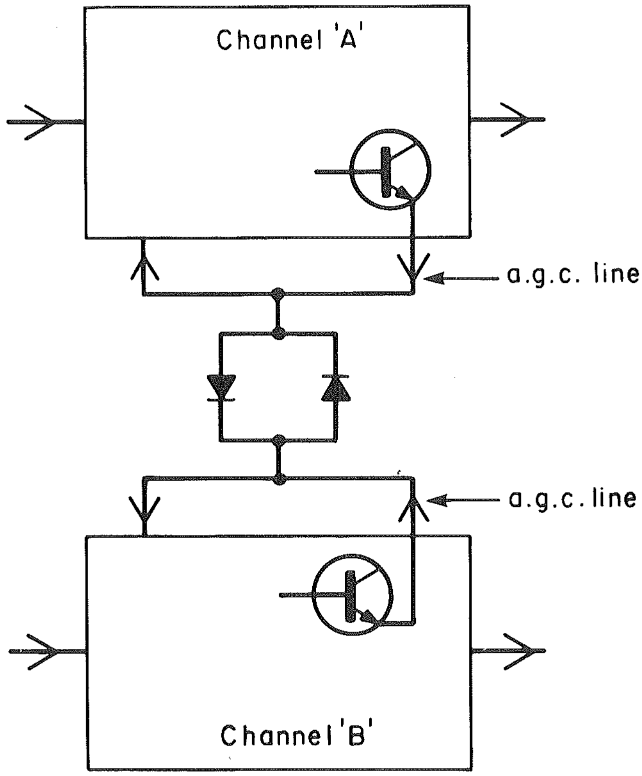

Fig. 3 - AGC combining circuit

control voltages and hence the receiver-channels cannot differ in gain by more than, say, 6 dB. This system is probably the best for a direct-adding audio combiner.

If the coupling capacitor is omitted but the anti-parallel diodes retained, as in Fig. 3, then the two channels will give equal audio output signal levels, over a ±6 dB range of relative inputs, but will cut-off the weaker channel for more severe fades. This type of a.g.c. link appears to be very suitable for the phase correlation combiner described in Section 6.

6. Audio-phase-correlation combining

In Section 3 it was stated that, by varying the phase of one of the audio signals before addition, it was possible to vary the frequencies of the nulls in the spectrum of the combined signal. If this phase between the two channels is continuously varied so that the principal audio-frequency components are kept in phase, then the nulls will fall at frequencies where there is little energy. In these circumstances, any frequency-selective distortion will be much less noticeable than if the null had occurred near the major component.

This method of combination forms the basis of the audio-phase-correlation combiner.*

6.1. Circuit description

As will be seen in the block diagram in Fig. 4 the two audio input signals A and B drive a pair of quadrature

* Modifications to achieve this mode of operation have been incorporated by the manufacturers in the Plessey receiver type PRD 200 A.

* BBC U.K. Patent Application No. 46928/75.

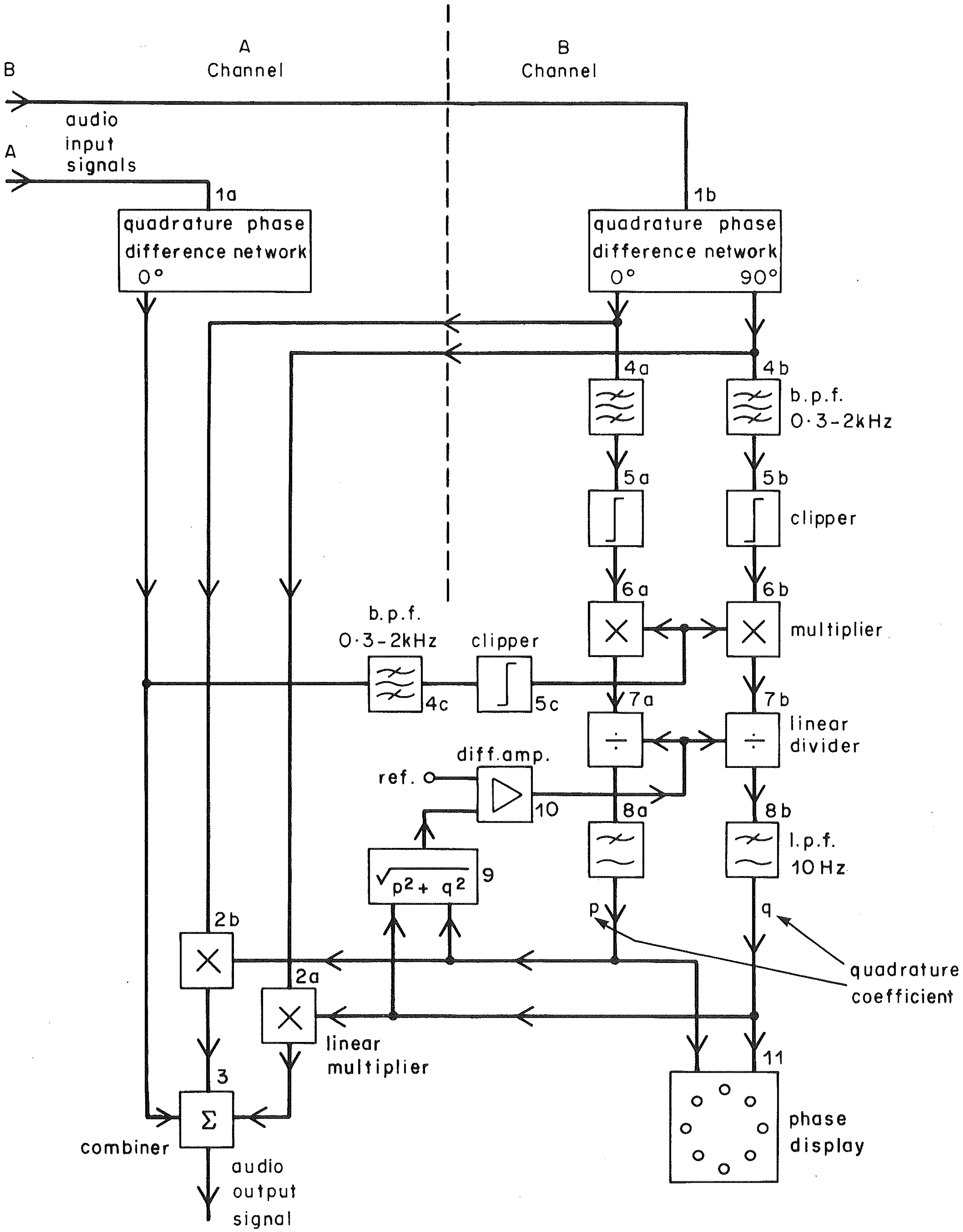

Fig. 4 - Combiner block diagram

phase-difference networks[1] (1a, 1b). Each of these networks has a pair of push-pull outputs with a quadrature phase relationship throughout the audio-frequency band of 80 Hz to 6 kHz. The signal output suffer an unavoidable additional phase-shift which increases with frequency and the purpose of the dummy network in the A channel is to balance this phase shift by introducing into the A signal path the same phase shift as that imposed on the nominal zero-phase output in the B path.

The outputs of the quadrature phase-difference networks are used for two main purposes. One is to provide the audio-programme signal feed to the linear multipliers (2a, 2b) and combiner (3), whilst the other is to feed the 300 Hz – 2 kHz bandpass filters (4a, 4b, 4c) followed by clippers (5a, 5b, 5c). The outputs of the clippers 5a and 5b in the B channel are multiplied by the output of A-channel clipper 5c in the multipliers 6a and 6b and the respective products are passed through low-pass filters 8a, 8b. (We ignore, for the moment, dividers 7a and 7b.) The outputs 'p' and 'q' from these filters represent the separate quadrature components of the complex correlation coefficient between the two audio input signals A and B. They are used by linear multipliers (2a, 2b) to control the levels of the B-channel signal quadrature-components that are added to the A-channel signal in the final combiner (3). The correlation coefficients p and q are also used to drive a ring of eight lamps (11) as a visual indication of the input signal phase relationships.

Under severe multipath conditions, the modulus of the complex correlation coefficient can fall appreciably; this would reduce both p and q and hence the contribution from the 'B' channel, if it were not compensated. Accordingly, the r.m.s. sum of the correlation coefficients p and q is computed (9) and compared with a reference signal in the differential amplifier (10). The result is used by the linear dividers (7a, 7b) to form an automatic level-control loop which maintains the modulus of the correlation coefficient at an approximately constant value.

In the event of a fade in one channel, or a pause in the programme, the correlation data could be lost and the circuit could restart with an arbitrary phase between the audio signals being combined if it were not for a 'cross-feed' unit, not shown in Fig. 4, for simplicity. This unit maintains the values of p and q close to the mean values which they held during the previous 30 seconds.

6.2. Further improvements

Further improvements to this circuit are at present under investigation. The first is to interchange automatically the two audio signal inputs, if necessary, so as to keep as the 'A' input the signal with the greater average level. The second will provide some compensation for the changes in the level of the output signal which can occur as the two input signals vary in relative level; this arises because two equal input signals, when added, give a higher output than a single input. This second improvement should, indirectly, lead to better quality because it should reduce the unwanted increases in dynamic range that can be caused by fading.

7. Subjective tests

Two series of subjective tests were carried out whilst the correlation combiner was being developed. During the tests, the combiner was not fitted with the 300 Hz-to-2 kHz bandpass filters in the correlator feeds (Fig. 4); this point is discussed in Section 8.

A short series of tests was first made, using the fading simulator described in the Appendix. These tests were mainly of an exploratory nature and the results were similar to the findings of the later tests; they are not therefore described in detail here.

The second main series of tests used dual-track audio tape recordings made at the BBC Far Eastern Relay station at Singapore of transmissions received from the UK using a Plessey PRD 200 dual-diversity receiver. This receiver was unmodified and so, although it was fitted with directly-linked a.g.c. circuits (see Section 5.2) it did not use the additional sideband a.g.c. circuits described in Section 5.1. Also, its synchronous detectors used the filtered carriers as the demodulating signal. Thus the receiver was not ideally suited to the new combiner but, nevertheless, was the best available.

The two tracks of the tape recorder carried the individual outputs from the two channels of the diversity receiver, thus permitting any audio combining methods to be tested.

The material used for the subjective tests consisted of excerpts from different types of programme in selective fading conditions and with each excerpt lasting for approximately 1½ minutes. Each observer switched between two conditions being compared and gave a judgement on a 7-point comparison scale.[2] The order of presentation was varied between items.

When selecting the excerpts, care was taken to avoid the passages where severe overloading had occurred since this was known to be due to the lack of sideband a.g.c. in the receiver at Singapore.

The first set of comparisons was made by fourteen observers. They made comparisons between the normal dual-diversity system and a single channel of the same system. From the outset, it was obvious that the differences between the two conditions would not be large; the validity of the comparisons was therefore checked by presenting, in some tests, identical conditions for the two cases. It was found that, as can be seen in Fig. 5, these 'no-difference' comparisons show an appreciable bias in favour of the first of the two conditions presented and a comparatively large spread in the results. During all the subsequent comparison tests, therefore, a random order of presentation of the two conditions was used in an attempt to reduce this bias. The results of comparisons between single-channel and dual-diversity reception are given in Fig. 6. These results show that there was little or no difference between dual-diversity and single-channel operation in conditions of selective fading. (It should be emphasised that the dual-diversity operation has considerable advantages in 'flat' fading con-

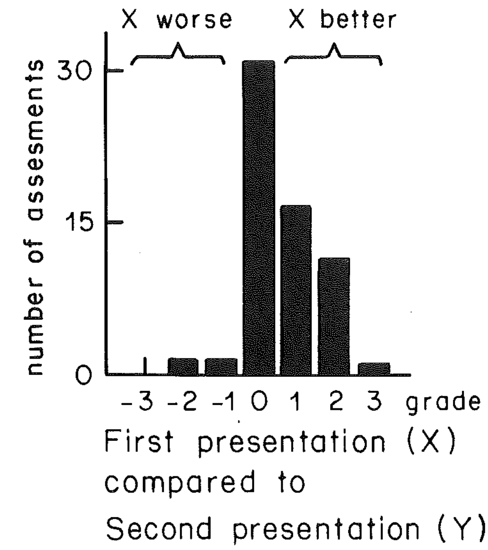

Fig. 5 - Comparison between identical conditions

grade
3 X much better than Y
2 X better than Y
1 X slightly better than Y
0 no difference
-1 X slightly worse than Y
-2 X worse than Y
-3 X much worse than Y

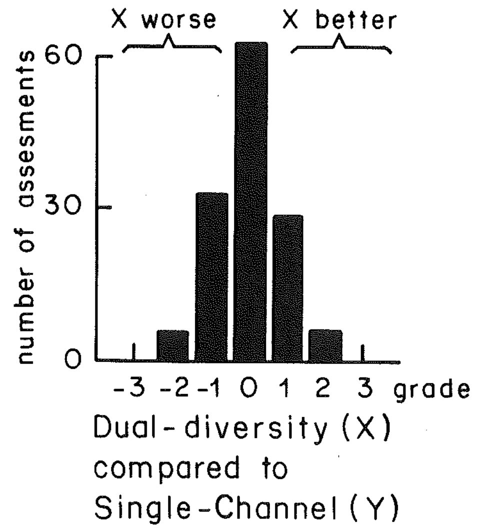

Fig. 6 - Comparison between dual-diversity (simple addition) and single-channel s.s.b. reception

ditions.) There is, of course, some spread of results arising from the difficulty of assessing the overall quality when there are drastic variations with time.

In the next set of subjective tests, again using material recorded in Singapore, the new correlation combiner was compared with single-channel operation as well as alternative forms of dual-diversity operation using four methods of combining the signals from the two channels. The first used direct addition of the two audio signals and the other three methods used a delay-line in one of the signal paths before addition. This method of combining the outputs of a diversity receiver through a delay-line was suggested in a CCIR Report;[3] delay values of 1, 2 or 3 ms were used. Fourteen observers were used for this series of subjective tests, each observer making a total of 25 comparisons. The results are summarised in Fig. 7.

It is seen from these results that there is an advantage of the order of one comparative grade for the new correlation combiner over single-channel reception; it also seems superior by between a half and one grade to the delay-line methods of combining. After each of the listening tests the observers were asked their general opinion of the tests and were given short runs with disclosed conditions. These observations agreed with later similar, but more extensive, tests with observers experienced in listening to h.f. rebroadcast circuits. The general opinion was that for at least 80% of the time there was little to choose between any of the systems except for the delay-line combining which was the worst under flat fading conditions. For the other 10 to 20% of the time there was a marked difference between the combining methods. It was also agreed that, when listening with the same passage repeated in the different combining modes, the new correlation combiner was never appreciably worse and usually better than any of the other combining systems.

8. Supplementary tests

Further tests with the fading simulator showed that improved tracking of rapid phase changes could be obtained by installing a 300 Hz-to-2 kHz bandpass filter in the feed to the correlator and reducing the correlator time-constants. This faster operation improved the response in flutter-fading conditions with no observable degradation in other conditions.

Once this faster method of operation has been achieved, a further benefit results which can be explained by the following argument.

(i) In two-channel diversity reception, a single common detecting-carrier cannot normally be used because of the rapid changes of relative phase that can occur between the r.f. signals in the two channels under conditions of frequency-selective fading. These cause the level of the combined audio output signal to vary according to the phase changes.

(ii) With separate detecting-carriers (derived from the received carriers), and under selective fading conditions, phase reversal of one of the received carriers can cause the corresponding audio output signal itself to suffer a phase-reversal. This effect is likely to cause an audible impairment to the combined audio output signal, the degree of which will depend upon the relative phases and levels of the audio signals in the two channels before the phase reversal.

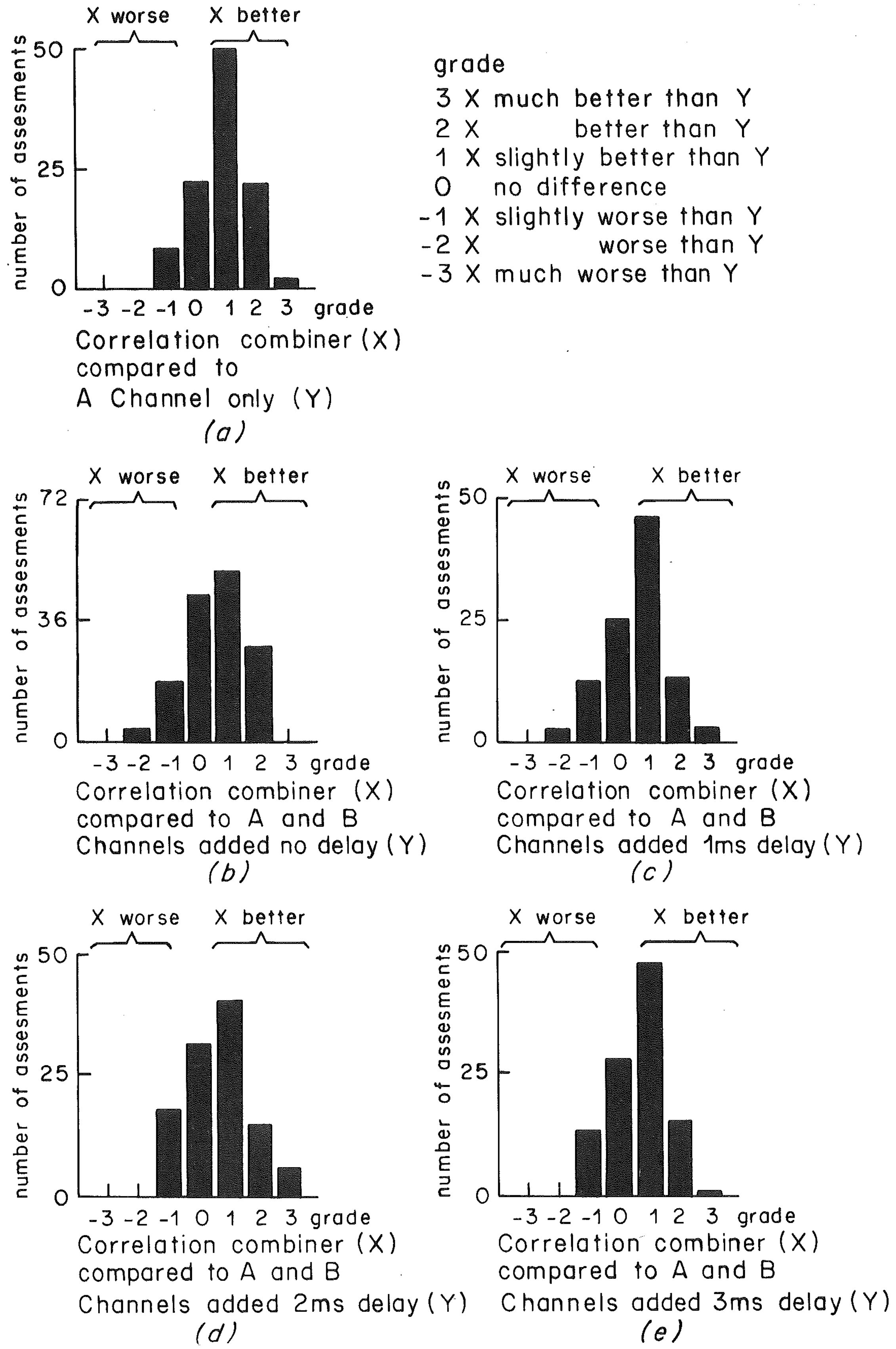

Fig. 7 - Comparisons between performances of new combiner and other methods of reception

(iii) The use of a fast-acting correlation combiner in diversity reception enables rapid phase-differences between the audio output signals from the two channels to be followed and corrected. This overcomes the difficulty in (i) above and therefore permits the use of a common detecting carrier (preferably obtained from a local frequency-synthesiser); in this case the impairment described in (ii) above would be avoided.

The use of a locally synthesised reference carrier for detection is also a benefit because it may lead to simpler receivers in the future.

Other tests have shown that, particularly when using diode-linked a.g.c. circuits, the proposed gain-compensation described in Section 6.2 gave appreciable advantages.

9. Conclusions

Under frequency-selective fading conditions, which often occur in relaying h.f. broadcasts, the conventional methods of combining dual-diversity signals may give only a small improvement over single-channel reception. A new experimental correlation audio combiner for use with diversity receivers has been described which shows, in laboratory tests, a considerable potential for the improvement of h.f. diversity reception. The results merit further work with an experimental combiner used under operational conditions.

10. Acknowledgements

Thanks are due to BBC External Broadcasting Department and the BBC Far Eastern Relay Station for the special recordings used for the subjective tests described in this Report.

11. References

1. GINGELL, M.J. 1973. Single-sideband modulation using sequence asymmetric polyphase networks. *Electrical Communications*, 1973, **48**, Nos. 1 and 2, pp. 21 – 25.

2. CCIR 1974 Report 623. Method proposed for the subjective assessment of the quality of sound in broadcasting and the performance of sound-programme transmission systems. XIIIth Plenary Assembly, Geneva, 1974, Vol. X, pp. 218 – 220.

3. CCIR 1970 Report 327-1. Diversity Reception. XIIth Plenary Assembly, New Delhi, 1970, Vol. 1, p. 193.

4. PACKER, R.J. *and* FOX, J.A.S. 1969. A simulator for ionsopheric propagation of amplitude modulated signals. BBC Research Department Report No. 1969/24.

Appendix

Fading Simulator

In order to simulate the effects of h.f. propagation through the ionosphere whilst using a diversity receiver, an earlier simulator[4] was modified to give two outputs. Fig. 8 is a block diagram of the equipment. Each of the fading signal outputs is the sum of six components. These components have slightly different carrier-frequencies and three of them have been passed through a delay of 0·25, 0·5, 1 or 2 ms, the value depending upon the setting of a delay selector. The two fading signal outputs use the same six basic components but the individual phases to the two summing amplifiers are made to differ in each case by means of six phase-shifters. These phase differences ensure that the fading pattern is different for each output, resembling dual spaced-aerial outputs for somewhat idealised two-path propagation.

Initial investigations used this simulator with swept-frequency audio-frequency modulation, the sweep covering 200 Hz to 6 kHz in 0·5 seconds.

SMW/AM

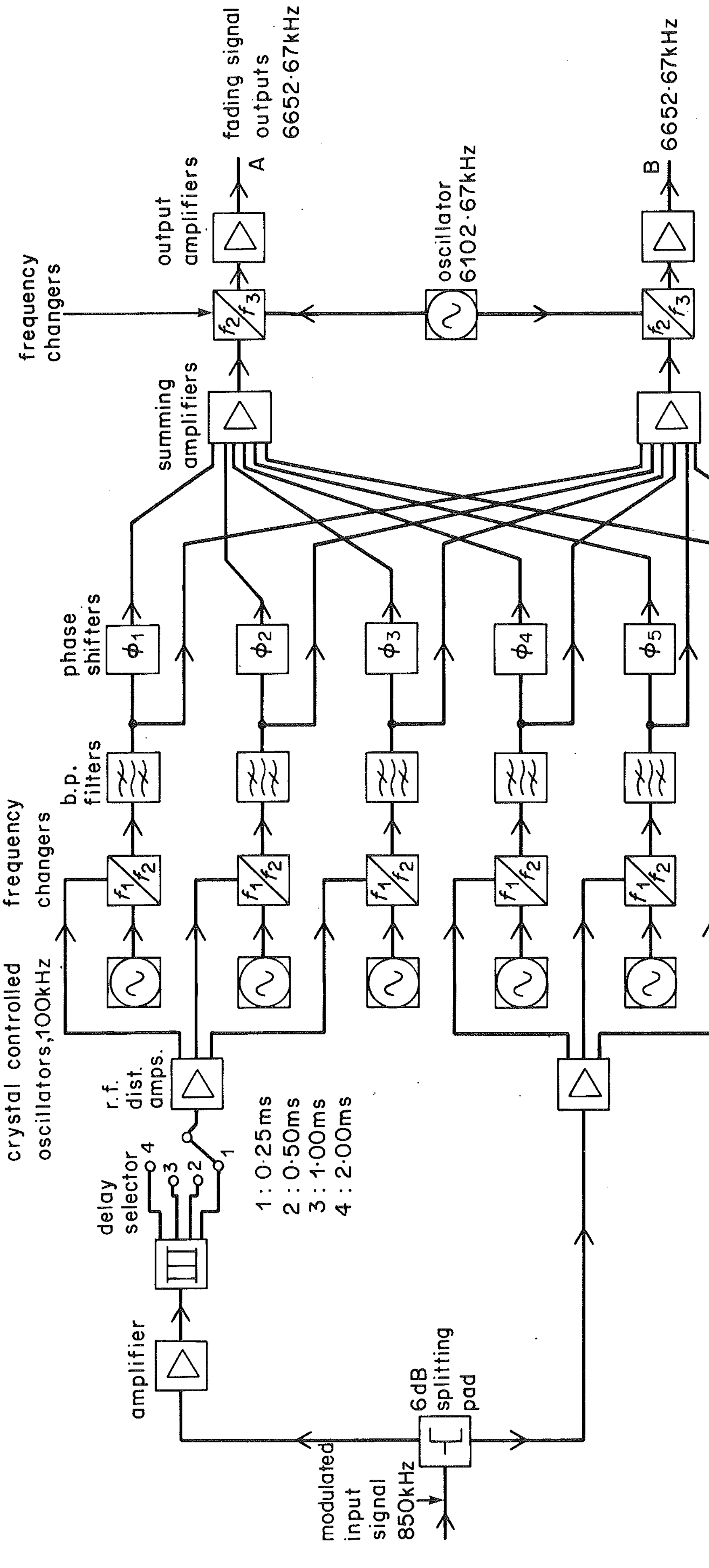

Fig. 8 - HF multipath simulator

Printed by BBC RESEARCH DEPARTMENT, Kingswood Warren, Tadworth, Surrey, KT20 6NP